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BIOLOGICAL WATER QUALITY MONITORING

SOUTHWEST MONTANA

1977 - 1978

by

Loren L. Bahls, Gary L. Ingman

and Abraham A. Horpestad

February 1979

State of Montana
Water Quality Bureau
Environmental Sciences Division
Department of Health and Environmental Sciences
Helena, Montana 59601



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ABSTRACT

Values for 30 biologically-related water quality parameters were measured seasonally at 17 stations on 16 streams in southwestern Montana from August 1977 to April 1978. Mean values for 16 key indicators were used to develop a composite water quality rating based on biological conditions.

Four stations had relatively poor water quality from the standpoint of stream biology: East Gallatin River near Belgrade, Muddy Creek near Dell, Prickly Pear Creek near Lake Helena, and Silver Bow Creek below the Warm Springs Ponds. All of these streams suffer from significant non-point pollution problems. Conditions at all but the Muddy Creek station are further aggravated by municipal wastewater discharges.

Most of the stations in the Southwest Loop had fair to good water quality. However, survey results cannot be considered representative of overall water quality, either in each stream or in southwestern Montana.



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PREFACE

The importance of long term monitors is evident when one considers the ecology of our biosphere, because it is being increasingly manipulated and polluted by the civilization of man. This is due to the increased population which results in an increased demand for materials for life and for habitation... (Patrick, 1977).

The national goal of fishable and swimmable water by 1983 is supported by the fact that water quality that permits these uses is also suitable for most other beneficial uses. This goal presumes that basic biological communities and processes that permit fishing and swimming will be maintained in a healthy balance. For example, it presumes that the small aquatic animals that fish eat will be present in variety and abundance, and it presumes that algae will not become a nuisance to boating, swimming, and fishing. Until recently, basic biological processes such as photosynthesis and aquatic life forms lower than fish had been given little consideration in water quality planning and management, yet these processes and life forms are basic to the integrity of the entire aquatic ecosystem. Any effects here on the "ground floor" likely will have repercussions on up the food chain.

Chemical and physical properties of water affect living organisms in ways we are just beginning to understand. Aquatic organisms are capable of integrating the many and diverse factors of their environment and of expressing their combined effect in terms of growth, reproductive success, and diversity. Aquatic organisms vary in their sensitivity to pollutants, hence some of the more sensitive and tolerant taxa have become useful as water quality indicators. Lower life forms are particularly useful as indicators because they are almost always present in statistically significant numbers.

To maintain water quality for fish and aquatic life is public policy of the State of Montana [Sec. 69-4801(1), R.C.M. 1947]. Pollution is defined in part as "contamination, or other alteration of the physical, chemical, or biological properties of any state waters . . ." [Sec. 69-4802(5), R.C.M. 1947]. To measure our success at protecting aquatic life and controlling pollution we need a good yardstick. What is a better yardstick than the biological organisms and processes themselves? Yet there has been no comprehensive, systematic, and continuing biological monitoring to date in Montana.

The Montana Biological Monitoring Program is designed to help fill this need. The program consists of a network of stations, a battery of parameters, and a sampling strategy.

The network includes 79 stations on 60 streams statewide, selected from completed water quality inventories and management plans (Water Quality Bureau, 1976) on the basis of likely improvement or degradation of water quality. Stations are grouped geographically into five loops, each with about 16 stations. Streams and stations in the network are listed in Appendix A. Sites monitored for biological parameters by the U. S. Geological Survey were considered in station selection in order to complement state and federal programs.



Data are gathered in seven biologically-related areas: streamflow, common ions (including specific conductance and total alkalinity), algal nutrients, algal growth response to nutrient additions (algal assay), periphyton production, periphyton community structure, and macroinvertebrate community structure.

Stations are monitored seasonally, once in summer, once in fall, and once in spring. Ice has proven to be a serious impediment to sampling. Consequently, winter sampling will not be pursued, even though it is a season of stress for aquatic organisms.

Realistically, with available manpower, only one or two loops can be monitored each year, hence each loop will be resampled every fourth or fifth year. Subsequent reports will evaluate changes in water quality over the intervening periods. Obviously, the program is not designed for rapid detection of acute problems but rather for evaluation of chronic, long-term trends.

Comments are welcome, especially now when the program is new. All stations, parameters, and procedures are on trial and subject to continuing evaluation. If we have overlooked a stream of particular interest to you, please let us know and give us your reasons why it should be included in the network. We would also like your comments on the overall usefulness of the program to you. It is hoped that these reports will be more than just internal planning and management documents, and that they will aid resource managers, municipalities, industries, and laymen in assessing water quality conditions and trends in their area.



INTRODUCTION

This is the first in a continuing series of reports on biological conditions in Montana rivers and streams.

The Southwest Loop includes some of the most popular and productive cold water fisheries in America. Also represented is a nearly complete cross-section of Montana water quality problems: sediment, temperature, dewatering, nutrients, coliforms, eutrophication, and acid mine drainage. The only major pollutant that is not a serious problem in southwestern Montana is salinity (Water Quality Bureau, 1976).

Stream stations covered in this report are listed in Table 1, along with station locations and abbreviations used in subsequent tables. All but four of the stations in the Southwest Loop are included in the Upper Missouri Tributaries drainage basin. Two stations, one on Silver Bow Creek and one on the upper Clark Fork River, are located in the Upper Clark Fork basin. The two stations on Prickly Pear Creek near Helena are located in the Missouri-Smith basin.

Parameters covered in this report are listed in Table 2. All parameters but common ions were collected seasonally, in August or September 1977 (summer), November or December 1977 (fall), and March or April 1978 (spring). Common ions were determined for the summer trip only.

The Southwest Loop is scheduled to be run again in 1981-1982. At that time changes in values of the different parameters can be compared and evaluation of long-term trends in water quality can begin. Meanwhile, the Water Quality Bureau will strive to develop a single, comprehensive, biological water quality index to simplify the rating of streams and the evaluation of trends.

Table 1. Stream stations covered in this report

Code	Description	Location
Beaverhead River	Beaverhead River at Twin Bridges	T03S R06W 27CAC
Big Hole River	Big Hole River near Twin Bridges	T03S R06W 29ACD
Boulder River	Boulder River below Boulder	T05N R04W 10DAC
Clark Fork River	Clark Fork River at Deer Lodge	T07N R09W 33CCD
East Gallatin River	East Gallatin River at Thompson Creek	T01N R04E 13ADD
Grasshopper Creek	Grasshopper Creek near mouth	T08S R10W 25CCB
Jefferson River	Jefferson River near Three Forks	T02N R01E 27BCC
Madison River	Madison River near Three Forks	T02N R02E 30ABC
Muddy Creek	Muddy Creek at mouth near Dell	T14S R10W 10AAC
Prickly Pear Creek/ Lake Helena	Prickly Pear Creek above Lake Helena	T10N R03W 03BBA
Prickly Pear Creek/ East Helena	Prickly Pear Creek at East Helena	T10N R03W 26DCC
Red Rock River	Red Rock River above Lima Res.	T14S R04W 06CDD
Ruby River	Ruby River near Twin Bridges	T04S R06W 10BAC
Sheep Creek	Sheep Creek above Muddy Creek	T14S R10W 10AAC
Silver Bow Creek	Silver Bow Creek below Warm Springs Ponds	T05N R09W 18DAC
West Fork Madison River	West Fork Madison River near mouth	T11S R01E 10DAA
West Gallatin River	West Gallatin River at Central Park	T01N R04E 19DBA

Table 2. Parameters covered in this report

Instantaneous Streamflow (m^3/sec)

Common Ions

- Cation Ratio : Ca:Mg:Na
- Anion Ratio : $HCO_3:SO_4:Cl$
- Specific Conductance (micromhos @25 C)
- Total Alkalinity (mg/l $CaCO_3$)

Algal Nutrients

- NO_2+NO_3-N ; NH_3-N ; Kjeldahl-N; PO_4-P ;
- Total P (all in mg/l)
- Total Soluable Inorganic Nitrogen (NO_2+NO_3-N plus NH_3-N):
- PO_4-P Ratio
- TSIN and Total P as % of recommended maximum instream levels
- (0.35 mg/l TSIN and 0.05 mg/l Total P)

Algal Assay

- Control
- Mean Maximum Standing Crop (MMSC) (mg/l)
- Statistical significance of MMSC
- Limiting Nutrient
- Nutrient Spike
- Mean Maximum Standing Crop (MMSC) (mg/l)
- Statistical significance of MMSC
- Limiting Nutrient

Periphyton Production

- Chlorophyll a Accrual ($mg/m^2/day$)
- Biomass Accrual ($mg/m^2/day$)
- Autotrophic Index
- Chlorophyll a/Pheophytin a Ratio ($OD663_b/OD663_a$)
- Carotene/Chlorophyll Ratio ($OD430/OD663$)

Periphyton Community Structure

- Rank of diatoms relative to other algae
- Percent Relative Abundance (PRA) of Major Diatom Species
- PRA *Achnanthes* species
- PRA *Nitzschia* species
- Number of Diatom Species
- Diatom Species Diversity ($\bar{d}$)

Macroinvertebrate Community Structure

- Mean PRA Major Macroinvertebrate Orders
- Mean PRA Tolerant, Facultative and Intolerant Macroinvertebrates
- Number of Macroinvertebrate Genera
- Macroinvertebrate Genus Diversity ($\bar{d}$)

RATIONALE, METHODS, RESULTS, AND INTERPRETATIONS

STREAMFLOW

Rationale

Accurate measurements of streamflow are essential for calculating loads of dissolved constituents, particularly nutrients. Many aquatic organisms have specific instream flow requirements for various activities. Exceptionally high and low flows -- overbank flooding and complete dewatering in the extremes -- are rather traumatic events for a river and its associated aquatic life. Periodic streamflow measurements also circumscribe a stream's size, which in turn dictates the nature of the aquatic community it can support.

Methods

Flow rates were measured with a Pygmy current meter in small streams and with a Price Type AA current meter in the larger streams. A straight section of stream with a uniform cross-section and a smooth bottom was chosen whenever available. A measuring tape was stretched across the channel and depths and velocities were recorded at selected points such that no more than 10 percent of the total discharge fell between two consecutive points. Total instantaneous discharge was then estimated by summing flows for each of the measured subsections.

Streamflow measurements on Sheep Creek and the East Gallatin River were provided by the U. S. Geological Survey. Measurements on Silver Bow Creek and the West Fork of the Madison River were obtained from records of the Anaconda Company and the U. S. Forest Service, respectively.

Results

Instantaneous streamflows are presented in Table 3.

Interpretation

Streamflow measurements are spotty because many of the rivers were too large to gage with available equipment. Summer flows averaged the lowest of the three seasons measured, while fall and spring flows were about equally high. The West Gallatin River was noticeably dewatered in summer 1977. At the other extreme, the Red Rock River was out of its banks during a spring 1978 visit. Muddy Creek was at least one order of magnitude smaller than all other streams in the Southwest Loop.

Table 3. Instantaneous Streamflow (m^3/sec)

Station	Summer	Fall	Spring	Mean
Beaverhead River	FNM	FNM	FNM	FNM
Big Hole River	FNM	FNM	FNM	FNM
Boulder River	0.48	1.30	5.47	2.42
Clark Fork River	1.47	7.59	FNM	4.53
East Gallatin River	5.67 (E)	FNM	FNM	5.67
Grasshopper Creek	0.17	FNM	2.44	1.30
Jefferson River	FNM	FNM	FNM	FNM
Madison River	FNM	FNM	FNM	FNM
Muddy Creek	0.03	FNM	0.06 (E)	0.04
Prickly Pear Creek/ Lake Helena	1.70	1.02 (E)	1.56	1.43
Prickly Pear Creek/ East Helena	0.57	0.82	1.16	0.85
Red Rock River	FNM	FNM	FNM	FNM
Ruby River	3.97	5.81	3.29 (E)	4.36
Sheep Creek	1.50	1.22	1.16	3.88
Silver Bow Creek	1.33	1.13	7.11	3.19
W. Fork Madison River	1.42	1.42	1.22	1.35
West Gallatin River	1.73	FNM	FNM	1.73
Mean	1.67	2.54	2.61	2.20

FNM: Flow not measured

(E): Estimate

COMMON IONS

Rationale

Common ions are the basic ingredients of the chemical "soup" in which aquatic organisms live. Their relative proportions often dictate the nature of plant and animal communities inhabiting surface waters. Specific conductance is a measure of osmotic stress on organisms -- both aquatic and terrestrial -- that live in, drink of, or are irrigated by the water in question. Total alkalinity measures the acid-neutralizing capacity of water. It is thus an indicator of a water's resiliency to acid and heavy metals pollution. It is also roughly proportional to a water's basic fertility or productivity.

Methods

Unpreserved and unfiltered grab samples were collected in one liter plastic bottles and transported under ice back to the laboratory. Analytical procedures followed the American Public Health Association (1971; 1975) or the U. S. Environmental Protection Agency (1974). Specific conductance was measured with a Wheatstone Bridge. Calcium and magnesium were measured by EDTA titration. Sodium was measured by atomic absorption. Bicarbonate and total alkalinity were measured by the automated methyl orange method or by titration with 0.02N H_2SO_4 to a pH 4.5 endpoint. Sulfate was determined by the automated turbidimetric method. Chloride was measured by the automated mercuric thiocyanate method or by mercuric nitrate titration.

Results

Common ion ratios and conductance and alkalinity values for the summer 1977 sampling run are presented in Table 4.

Interpretation

Two streams -- Muddy Creek and Silver Bow Creek -- had specific conductance values in excess of 1000 micromhos. In both cases these high conductivities were associated with disproportionately high concentrations of the sulfate ion. As a consequence, Silver Bow Creek, which had the highest conductance, also had the lowest alkalinity of all 16 streams in the Southwest Loop. The Clark Fork River at Deer Lodge was the third stream to have more sulfate than bicarbonate ion, no doubt from the influence of its tributary Silver Bow Creek. Calcium was the dominant cation in all streams except Muddy Creek and the Madison River, where sodium and calcium were codominants.

Table 4. Specific Conductance (μ mhos @25 C), Total Alkalinity (mg/l CaCO_3), and common ion ratios (as meq/l).

Station	Specific Conductance	Total Alkalinity	Ca:Mg:Na	$\text{HCO}_3:\text{SO}_4:\text{Cl}$
Beaverhead River	720	218	2:2:1	6:4:1
Big Hole River	271	116	3:1:1	22:4:1
Boulder River	227	72	5:1:1	19:9:1
Clark Fork River	766	159	5:1:1	9:14:1
East Gallatin River	418	195	6:3:1	32:4:1
Grasshopper Creek	400	161	4:1:2	12:3:1
Jefferson River	545	187	3:2:1	9:5:1
Madison River	321	114	2:1:2	6:1:1
Muddy Creek	1070	182	2:1:2	3:7:1
Prickly Pear Creek/ Lake Helena	460	153	3:1:1	7:3:1
Prickly Pear Creek/ East Helena	311	101	2:2:1	19:14:1
Red Rock River	303	142	2:2:1	21:2:1
Ruby River	658	235	3:2:1	19:9:1
Sheep Creek	532	158	5:3:1	18:15:1
Silver Bow Creek	1247	45	10:1:1	3:38:1
W. Fork Madison River	235	119	5:3:1	32:1:1
West Gallatin River	319	124	10:5:1	55:20:1
Mean	518	146		

ALGAL NUTRIENTS

Rationale

Nitrogen and phosphorus are the two elements most commonly limiting to algal growth in lakes and streams. Phosphorus is usually limiting in lakes because many common lake algae can use atmospheric nitrogen. Nitrogen-fixers are not common in streams, therefore this element is more often a limiting nutrient in flowing water. Only the soluble inorganic forms of these two nutrients -- nitrate, nitrite and ammonia nitrogen and ortho-phosphate -- are readily available for plant uptake. The sum of the soluble inorganic nitrogen fractions is called total soluble inorganic nitrogen or TSIN.

Some indication of whether nitrogen or phosphorus is growth limiting may be obtained by determining the weight ratio of the appropriate forms of nitrogen and phosphorus found in a river, and comparing that with the stoichiometric ratio required for growth (Zison et al., 1977). Specifically, let

$$R = \frac{[\text{TSIN}]}{[\text{PO}_4\text{-P}]}$$

where [TSIN] equals the concentration of total soluble inorganic nitrogen as N in mg/l and [PO₄-P] equals the concentration of phosphate as P in mg/l. If R is greater than 10, phosphorus is more likely limiting than nitrogen. If R is less than 5, nitrogen is more likely limiting than phosphorus. If R is less than 10 but greater than 5, it's a tossup as to which one is limiting. (See Table 5)

Nuisance growths of aquatic plants in streams usually can be avoided if total phosphorus is kept below 0.05 mg/l as P (Mackenthun, 1969) and if TSIN remains less than 0.35 mg/l as N (Muller, 1953). The phosphorus criterion is particularly applicable if the stream enters a standing body of water, which is eventually true of all streams in the Southwest Loop. If instream phosphorus and TSIN values are computed as a percentage of these critical levels, as they are in Tables 6 and 7, the algae growth potential of these waters can be assessed. Nuisance growths can be expected where both P and TSIN are significantly greater than 100 percent of the critical levels, other factors being amenable to algae growth.

Methods

Unfiltered grab samples were collected in separate one liter plastic bottles, each preserved with 4 ml of HgCl₂ and transported under ice back to the laboratory. Analytical procedures followed the American Public Health Association (1971; 1975) or the U. S. Environmental Protection Agency (1974). Orthophosphate was measured by automated ascorbic acid reduction. Total phosphorus was determined by persulfate digestion followed by automated ascorbic acid reduction. Nitrate plus nitrite nitrogen was measured by the hydrazine reduction method. (Future analyses will be done by the automated cadmium reduction method.) Ammonia was measured by the automated phenolate method. Total Kjeldahl nitrogen was determined by manual digestion followed by the automated phenolate procedure.

Results

Measured algal nutrient levels for the 1977-1978 sampling season are listed in Appendixes B through F. TSIN-phosphate phosphorus ratios are presented in Table 5. Tables 6 and 7 give instream TSIN and total phosphorus values as percentages of maximum recommended instream concentrations.

Interpretation

It is apparent from Table 5 that nutrient ratios are variable from season to season, trending toward relatively more nitrogen availability in fall than in spring and summer. Based on data pooled over all three seasons, four rivers are phosphorus limited: Beaverhead, Clark Fork, Jefferson and Ruby. (The Jefferson may be nitrogen limited in summer and spring, however.) By the same token, seven streams appear to be nitrogen limited: Big Hole, Boulder, Grasshopper Creek, Madison, Muddy Creek, Prickly Pear Creek (above Lake Helena), and the Red Rock River. The limiting nutrient at the remaining six stations is either seasonally variable or not determinable because of intermediate nutrient ratios, i.e., $10 > R > 5$. These stations must await confirmation from the algal assay tests.

Five streams have mean nitrogen and phosphorus levels significantly in excess of recommended instream concentrations (Tables 6 and 7). These streams are the Beaverhead, Clark Fork and East Gallatin rivers, Silver Bow Creek, and Prickly Pear Creek above Lake Helena. Each of these streams is capable of producing nuisance algal growths at certain times of the year, assuming other growth factors are favorable. Five additional streams have excess phosphorus only, but could produce nuisance growths given substantial inputs of nitrogen. These waters are the Big Hole, Boulder, and Red Rock rivers and Grasshopper and Muddy creeks.

Table 5. Ratio of total soluble inorganic nitrogen ($\text{NO}_2 + \text{NO}_3 - \text{N}$ plus $\text{NH}_3 - \text{N}$) to phosphate phosphorus (PO_4 as mg/l P)²

Station	Summer	Fall	Spring	Mean * (Pooled)
Beaverhead River	116:1	61:1	16:1	36:1
Big Hole River	<1:1	<1:1	1:1	<1:1
Boulder River	6:1	4:1	3:1	4:1
Clark Fork River	70:1	45:1	10:1	16:1
East Gallatin River	5:1	6:1	5:1	5:1
Grasshopper Creek	1:8	2:1	2:1	2:1
Jefferson River	<10:1	54:1	5:1	12:1
Madison River	<1:1	1:1	2:1	1:1
Muddy Creek	1:1	Ice	1:3	1:3
Prickly Pear Creek/ Lake Helena	3:1	6:1	3:1	4:1
Prickly Pear Creek/ East Helena	6:1	11:1	10:1	10:1
Red Rock River	3:1	Ice	1:1	1:1
Ruby River	50:1	73:1	9:1	16:1
Sheep Creek	10:1	13:1	4:1	6:1
Silver Bow Creek	10:1	85:1	5:1	9:1
W. Fork Madison River	<1:1	8:1	4:1	5:1
West Gallatin River	<2:1	18:1	3:1	5:1
Mean* (Pooled)	5:1	8:1	4:1	5:1

*Assumes concentrations less than 0.01 equal zero

Table 6. Total soluble inorganic nitrogen ($\text{NO}_2 + \text{NO}_3$ -N plus NH_3 -N) as a percentage of the recommended maximum instream level (0.35 mg/l)

Station	Summer	Fall	Spring	Mean*
Beaverhead River	166	157	146	156
Big Hole River	< 3	< 3	14	5
Boulder River	26	43	60	43
Clark Fork River	80	191	274	182
East Gallatin River	177	300	297	258
Grasshopper Creek	3	37	100	47
Jefferson River	< 3	77	40	39
Madison River	< 3	6	17	8
Muddy Creek	3	Ice	17	10
Prickly Pear Creek/ Lake Helena	277	1366	360	668
Prickly Pear Creek/ East Helena	20	63	80	54
Red Rock River	6	Ice	14	10
Ruby River	14	63	69	49
Sheep Creek	6	23	23	17
Silver Bow Creek	14	243	243	167
W. Fork Madison River	< 3	46	37	28
West Gallatin River	< 3	26	26	17
Mean*	47	176	107	107

*Assumes concentrations less than 0.01 equal zero

Table 7. Total phosphorus as a percentage of the recommended maximum instream level (0.05 mg/l)

Station	Summer	Fall	Spring	Mean
Beaverhead River	44	80	234	119
Big Hole River	50	140	270	153
Boulder River	44	80	226	117
Clark Fork River	40	220	462	241
East Gallatin River	300	400	642	447
Grasshopper Creek	220	120	744	361
Jefferson River	32	60	146	79
Madison River	50	40	106	65
Muddy Creek	52	Ice	1066	559
Prickly Pear Creek/ Lake Helena	920	3200	1034	1718
Prickly Pear Creek/ East Helena	48	40	124	71
Red Rock River	114	Ice	240	177
Ruby River	28	40	216	95
Sheep Creek	34	20	68	41
Silver Bow Creek	40	100	628	256
W. Fork Madison River	36	60	100	65
West Gallatin River	20	40	74	45
Mean	122	309	375	267

ALGAL ASSAY

Rationale

The algal assay is based on Liebig's law of the minimum, which states that "growth is limited by the substance that is present in minimal quantity with respect to the needs of the organism" (U.S.E.P.A., 1971). Algal assays are used: 1) to confirm or refute conclusions regarding limiting nutrients based on N/P ratios; 2) to determine biologically the availability of algal growth-limiting nutrients; 3) to quantify biological response to change in concentrations of algal growth-limiting nutrients; and 4) to determine whether various compounds or water samples are toxic or inhibitory to algae. The basic reasons for including algal assays in this monitoring program are to determine each stream's algal growth potential and sensitivity to additions of algal nutrients.

Methods

Algal assays were conducted following "bottle test" procedures published by the U. S. Environmental Protection Agency (1971). The unicellular green alga Selenastrum capricornutum Printz was used as the test alga. Combined nutrient spikes were of two types: Type A spikes consisted of 0.03 mg/l P plus 0.50 mg/l N and Type B spikes consisted of 0.10 mg/l P plus 1.00 mg/l N. Only one or the other of these spikes was used on a given water sample. (Spikes with a chelating agent, i.e., EDTA, to test for algal growth inhibition by heavy metals, were not applied in this instance but will be applied in all future assays.) Three replicates were run on each treatment, i.e., control and combined nutrient spike. Maximum standing crop was measured and reported in terms of mg/l dry weight, averaged over the three replicates. Theoretical maximum standing crop (TMSC) was determined by multiplying measured ortho-P and TSIN values by the appropriate production coefficient (430 and 38, respectively) and by taking the lesser of the two resulting values. Statistical reliability of mean maximum standing crop (MMSC) results as compared to theoretical maximum standing crop (TMSC) was determined from coefficient of variance criteria presented by Miller et al. (1978):

- ± 50% for TMSC < 1.00 mg/l
- ± 30% for TMSC > 1.00 but < 3.00 mg/l
- ± 20% for TMSC > 3.00 but < 10.00 mg/l
- ± 10% for TMSC > 10.00 mg/l

Low MMSC values that are significantly different could be due to: 1) micro-nutrients limiting; 2) something toxic or inhibitory in the water sample; and/or 3) nutrients incorrectly overestimated in analysis. High values that are significantly different could be the result of incorrectly underestimating nutrients in analysis.

Results

Algal assay results for summer and fall 1977 and spring 1978 are presented in tables 8, 9, and 10, respectively.

Table 8. Algal assay results, summer 1977

Station	Control			Nutrient Spike			
	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient	Type	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient
Beaverhead River	0.36	Yes-Low	P	A	5.73	Yes-Low	P
Big Hole River	0.67	No	N	A	7.84	Yes-Low	P
Boulder River	0.61	Yes-Low	N	A	3.94	Yes-Low	P
Clark Fork River	0.56	Yes-Low	P	A	11.78	Yes-Low	P
East Gallatin River	16.83	Yes-Low	N	B	54.36	Yes-Low	N
Grasshopper Creek	7.88	Yes-High	N	A	11.51	Yes-Low	N
Jefferson River	0.52	No	N	B	36.87	No	N
Madison River	0.25	No	N	B	37.31	No	N
Muddy Creek	0.37	No	P or N	A	6.14	Yes-Low	P
Prickly Pear Creek/ Lake Helena	30.23	Yes-Low	N	B	52.72	Yes-Low	N
Prickly Pear Creek/ East Helena	0.70	Yes-Low	N	B	22.26	Yes-Low	N
Red Rock River	10.38	No	P	A	15.67	Yes-Low	P
Ruby River	0.33	No	P	A	9.21	Yes-Low	P
Sheep Creek	0.28	Yes-Low	P or N	A	0.59	Yes-Low	P
Silver Bow Creek	0.45	Yes-Low	P	A	8.48	Yes-Low	P
W. Fork Madison River	1.12	No	N	A	5.58	Yes-Low	P
West Gallatin River	0.52	No	N	B	56.96	Yes-High	N

Type A: 0.03 mg/l P +
0.50 mg/l N

Type B: 0.10 mg/l P +
1.00 mg/l N

Table 9. Algal assay results, fall 1977

Station	Control			Nutrient Spike			
	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient	Type	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient
Beaverhead River	0.47	Yes-Low	P	B	59.76	Yes-High	P
Big Hole River	0.56	No	N	B	5.11	Yes-Low	N
Boulder River	12.15	Yes-High	N	B	45.20	No	N
Clark Fork River	-----SAMPLE LOST-----				-----SAMPLE LOST-----		
East Gallatin River	55.82	Yes-High	N	B	94.14	Yes-High	N
Grasshopper Creek	8.34	Yes-High	N	B	28.10	Yes-Low	N
Jefferson River	-----ICE-----				-----ICE-----		
Madison River	0.25	Yes-Low	N	B	42.30	No	N
Muddy Creek	-----ICE-----				-----ICE-----		
Prickly Pear Creek/ Lake Helena	128.5	Yes-Low	N	B	174.8	Yes-Low	N
Prickly Pear Creek/ East Helena	0.55	Yes-Low	N	B	4.67	Yes-Low	N
Red Rock River	-----ICE-----				-----ICE-----		
Ruby River	0.63	Yes-High	P	B	43.42	No	P
Sheep Creek	0.98	Yes-Low	P	B	59.90	Yes-High	N
Silver Bow Creek	1.07	Yes-Low	P	B	47.80	No	P
W. Fork Madison River	-----ICE-----				-----ICE-----		
West Gallatin River	-----SAMPLE LOST-----				-----SAMPLE LOST-----		

Type A: 0.03 mg/l P +
0.50 mg/l N

Type B: 0.10 mg/l P +
1.00 mg/l N

Table 10. Algal assay results, spring 1978

Station	Control			Nutrient Spike			
	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient	Type	Mean Maximum Standing Crop (mg/l)	Significantly Different from TMSC?	Limiting Nutrient
Beaverhead River	1.65	Yes-Low	P	B	50.04	Yes-Low	P
Big Hole River	3.72	Yes-High	N	B	70.87	Yes-High	N
Boulder River	9.66	Yes-High	N	B	75.08	Yes-High	N
Clark Fork River	-SAMPLE LOST-				-SAMPLE LOST-		
East Gallatin River	-SAMPLE LOST-				-SAMPLE LOST-		
Grasshopper Creek	1.12	Yes-Low	N	B	50.25	No	N
Jefferson River	0.49	Yes-Low	P	B	0.49	Yes-Low	N
Madison River	0.65	Yes-Low	N	B	40.85	No	N
Muddy Creek	4.80	Yes-High	N	B	59.90	Yes-High	N
Prickly Pear Creek/ Lake Helena	83.72	Yes-High	N	B	154.44	Yes-High	N
Prickly Pear Creek/ East Helena	5.98	Yes-Low	N	B	76.38	Yes-High	N
Red Rock River	2.31	No	N	B	39.00	No	N
Ruby River	-SAMPLE LOST-				-SAMPLE LOST-		
Sheep Creek	0.94	Yes-Low	N	B	38.09	No	N
Silver Bow Creek	0.52	Yes-Low	P or N	B	0.58	Yes-Low	N
W. Fork Madison River	-SAMPLE LOST-				-SAMPLE LOST-		
West Gallatin River	-SAMPLE LOST-				-SAMPLE LOST-		

Type A: 0.03 mg/l P +
0.50 mg/l N
Type B: 0.10 mg/l P +
1.00 mg/l N

Interpretation

The algal assay data substantiate or clarify the nutrient limitation predictions based on nitrogen to phosphorus ratios. Of these two nutrients, phosphorus was in short supply (limiting) in the assay water relative to the needs of the test alga (*Selenastrum capricornutum*) for the following streams: Beaverhead, Clark Fork, and Ruby rivers, and Silver Bow Creek. Nitrogen was limiting in the Big Hole, Boulder, East Gallatin, Madison and West Fork Madison rivers, and in Grasshopper, Muddy, and Prickly Pear creeks. In the remaining streams, nitrogen and phosphorus are co-limiting and/or they exchange the role of limiting nutrient from season to season. The fact that mean maximum standing crop was significantly less than theoretical maximum standing crop in the majority of assays may indicate that micronutrients were limiting or toxic substances were inhibiting algal growth in at least some of the streams of the Southwest Loop. Independent evidence suggests that heavy metals may be toxic to algae above the Warm Springs Ponds and that trace elements may be in short supply (limiting) below the ponds on Silver Bow Creek (Frieling, 1977).

PERIPHYTON PRODUCTION

Rationale

Periphyton is the community of plants and animals, most of them microscopic, living attached to or in close proximity of the stream bottom. In terms of primary production -- converting solar energy to plant biomass -- it is the most important community in the majority of Montana streams.

Measuring the growth of periphyton organisms on artificial substrates placed in a stream is one method of estimating the productive potential of the stream. The two parameters most commonly measured are chlorophyll a (the most significant photosynthetic pigment) and ash-free weight or biomass. Measurements of these parameters have been made on a great variety of surface waters worldwide and in Montana. Chlorophyll accrual rates in Montana streams have been summarized by Klarich (1976). An assessment of a stream's trophic status can be made by comparing its rate of accrual to rates in other waters known to be oligotrophic, mesotrophic or eutrophic.

The autotrophic index (AI) is the mass ratio of biomass to chlorophyll a. Chlorophyll a usually contributes from 1 to 2 percent of algal dry weight, resulting in AI values of 50 to 100 in pure algal cultures. As a stream is enriched with organic compounds the proportion of consuming, non-chlorophyll bearing organisms increases and the fraction of autotrophic, chlorophyll bearing organisms (algae) decreases. Unpolluted stream AI values normally range from 50 to 200. Larger AI values indicate poor water quality (A.P.H.A., 1975).

The amount of pheophytin a in a periphyton sample relative to the amount of chlorophyll a is an indicator of the physiological condition of the algae. Pheophytin a is derived from chlorophyll a upon breakdown and loss of magnesium ion. Acidification in the laboratory has the same effect. Acidification of a solution of pure chlorophyll a results in a 40 percent reduction in optical density, yielding a before/after acidification ratio of about 1.7. Field samples with a ratio of 1.7 are considered to contain little if any pheophytin a and to be in excellent physiological condition. Solutions of pure pheophytin show no reduction in optical density upon acidification and have a before/after ratio of 1.0. Thus, mixtures of chlorophyll a and pheophytin a have optical density ratios ranging between 1.0 and 1.7 (A.P.H.A., 1975).

The ratio of yellow pigment (carotene) to green pigment (chlorophyll) in a sample of mixed algae can be used as an index of community stability and productivity (Margalef, 1969). In young, vigorously growing algal communities the green photosynthetic pigment chlorophyll a predominates and the yellow to green optical density ratio is low, usually about 2. As the community ages and becomes more diversified, yellow pigments predominate and the yellow to green ratio increases to 3 or greater (Odum, 1963).

Methods

Artificial substrates (glass microscope slides) were used to measure the accrual of periphyton pigments and biomass. The slides were placed in a

plastic carriage (Periphytometer II) produced by Design Alliance, Inc. of Cincinnati, Ohio. The carriage and slides ensemble was tied to a cement cinder block, which served as an anchor. The sampling device was placed in water of moderate current velocity (0.1 to 0.5 m/sec) and moderate depth (0.3 to 1.0 m) such that the slides were oriented vertically with their surfaces perpendicular to the direction of flow. The slides were exposed from 13 to 28 days depending on season, water temperature and inherent productivity.

Upon retrieval, the slides were removed from the carriage and immediately placed into light-proof slide boxes. The boxes were labelled and transferred to the laboratory on ice. On arrival at the lab, the boxes were placed in a freezer for at least 24 hours to enhance cell lysis.

Pigment extraction and measurement were then performed according to the American Public Health Association (1975) with the following procedural exceptions. Periphyton was scraped into 50 ml, foil wrapped centrifuge tubes. For each slide scraped, 10 ml of 90 percent acetone-10 percent saturated $MgCO_3$ solution was added to the tube. Usually, one sample consisted of scrapings from 4 slides, consequently the total acetone volume equalled 40 ml. The tubes were placed in a sonic bath for at least 20 minutes to aid pigment extraction and then allowed to steep for at least 24 hours in the dark under refrigeration at 4 °C. Pigment optical density readings were made with a Perkin-Elmer Model 200 Spectrophotometer at a resolution setting of 1.0 nanometer.

Biomass determinations were also made according to the A.P.H.A. (1975) with the following variations. Biomass and chlorophyll were measured on separate slides for the summer 1977 run but the same material was used for both measurements during the fall 1977 and spring 1978 runs. Inconel alloy metal crucibles were used. Prior to placing the samples in the drying oven, the acetone was evaporated under a bank of sun lamps.

Results

Tables 11 through 15 contain chlorophyll a accrual rates, biomass accrual rates, autotrophic index values, chlorophyll a/pheophytin a ratios, and carotene/chlorophyll ratios, respectively.

Interpretation

Chlorophyll a accrual rates in streams of southwestern Montana averaged from 0.08 to 2.69 $mg/m^2/day$ (Table 11). Klarich (1976) reported mean accrual values ranging from 0.7 at Laurel to 12.2 at Huntley for a stretch of the Yellowstone River he describes as "mesotrophic". Bahls (1978) found two very oligotrophic streams in northwestern Montana to have mean chlorophyll a accrual rates of 0.13 and 0.14 $mg/m^2/day$. Streams of the Southwest Loop might thus be rated from oligotrophic to mesotrophic, with Red Rock River least productive and the East Gallatin most productive in terms of chlorophyll a accrual. Caution should be used, however, because of the many missing data points.

Mean biomass accrual rates in streams of the Southwest Loop ranged from a low of 28 mg/m²/day in the Clark Fork River at Deer Lodge to a high of 414 mg/m²/day in the East Gallatin River at Thompson Creek (Table 12). Klarich (1976) reported extreme values of 50 and 730 mg/m²/day in the Yellowstone River above and below Billings, respectively. Bahls (1978) reported mean biomass accrual rates of 115 and 102 mg/m²/day for the two oligotrophic northwestern Montana streams. Normal biomass production rates for streams range from 300 to 4,100 mg/m²/day, according to Whittaker (1970). Consequently, biomass accrual in southwest Montana streams falls toward the low end of the stream productivity spectrum, substantiating the oligotrophic to mesotrophic classifications applied on the basis of chlorophyll *a* accrual. Again, caution should be used because of missing data and because existing stream vegetation may compete with colonizing algae for available nutrients.

Mean autotrophic index values ranged from 132 (Ruby River) to 1538 (Red Rock River). Satisfactory mean values were recorded for the Beaverhead, Boulder, East Gallatin, Ruby, West Fork Madison, and West Gallatin rivers and for Sheep Creek. All other mean values were significantly in excess of 200, indicating poor water quality. Once again, caution should be used in interpreting these results because of inadequate data.

Mean chlorophyll *a*/pheophytin *a* ratios ranged from 1.23 (Red Rock River) to 1.61 (Prickly Pear Creek above Lake Helena) with an overall mean of 1.51 (Table 14). This seems to indicate that, with the exception of the Red Rock River, the physiological condition of algae colonizing artificial substrates in southwest Montana streams is fair to good.

Mean "yellow/green" or carotene/chlorophyll ratios were between 2.39 (Sheep Creek) and 11.93 (Big Hole River) (Table 15). The East Gallatin River was the only other stream with a mean ratio less than 3.00. Consequently, all streams but Sheep Creek and the East Gallatin can be said to have stable, mature floras. However, neither of these streams were sampled for algal pigments in spring, and spring ratios were consistently larger than fall ratios, perhaps indicating a maturing of the floras over winter. It would be expected that the summer, post-scour floras would have even smaller pigment ratios than the fall floras.

Table 11. Chlorophyll a accrual ($\text{mg}/\text{m}^2/\text{day}$)

Station	Summer	Fall	Spring	Mean
Beaverhead River	1.37	DNA	0.47	0.92
Big Hole River	1.65	DNA	0.10	0.88
Boulder River	1.26	0.24	0.07	0.52
Clark Fork River	1.78	0.04	0.36	0.73
East Gallatin River	4.10	1.28	DNA	2.69
Grasshopper Creek	0.25	DNA	DNA	0.25
Jefferson River	0.62	DNA	0.29	0.46
Madison River	0.18	DNA	0.03	0.10
Muddy Creek	0.14	DNA	DNA	0.14
Prickly Pear Creek/ Lake Helena	DNA	0.01	0.32	0.16
Prickly Pear Creek/ East Helena	0.30	0.02	1.01	0.44
Red Rock River	0.08	DNA	DNA	0.08
Ruby River	DNA	0.82	1.41	1.12
Sheep Creek	1.13	1.22	DNA	1.18
Silver Bow Creek	1.62	DNA	DNA	1.62
W. Fork Madison River	1.76	0.08	4.09	1.98
West Gallatin River	1.68	0.37	0.20	0.75
Mean	1.19	0.45	0.76	0.87

DNA: Data not available

Table 12. Biomass accrual ($\text{mg}/\text{m}^2/\text{day}$)

Station	Summer	Fall	Spring	Mean
Beaverhead River	367	DNA	95	231
Big Hole River	341	DNA	41	191
Boulder River	245	38	17	100
Clark Fork River	9	22	53	28
East Gallatin River	716	111	DNA	414
Grasshopper Creek	121	DNA	DNA	121
Jefferson River	436	DNA	39	238
Madison River	52	DNA	13	32
Muddy Creek	162	DNA	DNA	162
Prickly Pear Creek/ Lake Helena	DNA	14	163	88
Prickly Pear Creek/ East Helena	114	17	167	99
Red Rock River	112	DNA	DNA	112
Ruby River	DNA	58	272	165
Sheep Creek	285	80	DNA	182
Silver Bow Creek	DNA	DNA	DNA	DNA
W. Fork Madison River	190	9	953	384
West Gallatin River	386	49	54	163
Mean	253	44	170	171

DNA: Data not available

Table 13. Autotrophic index

Station	Summer *	Fall**	Spring **	Mean
Beaverhead River	257	DNA	209	233
Big Hole River	207	DNA	416	312
Boulder River	194	153	255	201
Clark Fork River	DNA	632	149	390
East Gallatin River	174	93	DNA	134
Grasshopper Creek	517	DNA	DNA	517
Jefferson River	688	DNA	171	430
Madison River	329	DNA	402	366
Muddy Creek	1156	DNA	DNA	1156
Prickly Pear Creek/ Lake Helena	DNA	1858	539	1198
Prickly Pear Creek/ East Helena	474	788	169	477
Red Rock River	1538	DNA	DNA	1538
Ruby River	DNA	73	192	132
Sheep Creek	253	60	DNA	156
Silver Bow Creek	DNA	DNA	DNA	DNA
W. Fork Madison River	107	108	236	150
West Gallatin River	232	132	276	213
Mean	471	433	274	395

*Biomass and chlorophyll measurements on separate slides

**Biomass and chlorophyll measurements on same slide(s)

DNA: Data not available

Table 14. Chlorophyll a /Pheophytin a ratio
(OD663_b/OD663_a)

Station	Summer	Fall	Spring	Mean
Beaverhead River	1.24	DNA	1.71	1.48
Big Hole River	1.63	DNA	1.50	1.56
Boulder River	1.61	DNA	1.60	1.60
Clark Fork River	1.56	DNA	1.60	1.58
East Gallatin River	1.39	1.48	DNA	1.44
Grasshopper Creek	DNA	DNA	DNA	DNA
Jefferson River	1.44	DNA	1.65	1.54
Madison River	1.58	DNA	1.63	1.60
Muddy Creek	DNA	DNA	DNA	DNA
Prickly Pear Creek/ Lake Helena	DNA	DNA	1.61	1.61
Prickly Pear Creek/ East Helena	1.52	DNA	1.60	1.56
Red Rock River	1.23	DNA	DNA	1.23
Ruby River	DNA	1.56	1.43	1.50
Sheep Creek	1.33	1.54	DNA	1.44
Silver Bow Creek	DNA	DNA	DNA	DNA
W. Fork Madison River	1.37	DNA	1.48	1.42
West Gallatin River	1.39	1.57	1.62	1.53
Mean	1.44	1.54	1.58	1.51

DNA: Data not available

Table 15. Carotene/Chlorophyll ratio
(OD430/OD 663)

Station	Summer	Fall	Spring	Mean
Beaverhead River	DNA	DNA	10.10	10.10
Big Hole River	DNA	DNA	11.93	11.93
Boulder River	DNA	2.12	9.04	5.58
Clark Fork River	DNA	2.33	9.54	5.94
East Gallatin River	DNA	2.51	DNA	2.51
Grasshopper Creek	DNA	DNA	DNA	DNA
Jefferson River	DNA	DNA	10.64	10.64
Madison River	DNA	DNA	7.12	7.12
Muddy Creek	DNA	DNA	DNA	DNA
Prickly Pear Creek/ Lake Helena	DNA	3.00	9.14	6.07
Prickly Pear Creek/ East Helena	DNA	2.21	6.59	4.40
Red Rock River	DNA	DNA	DNA	DNA
Ruby River	DNA	2.54	4.30	3.42
Sheep Creek	DNA	2.39	DNA	2.39
Silver Bow Creek	DNA	DNA	DNA	DNA
W. Fork Madison River	DNA	2.20	5.20	3.70
West Gallatin River	DNA	2.66	10.03	6.34
Mean	DNA	2.44	8.51	5.78

DNA: Data not available

Rationale

Except in the lower reaches of our largest rivers -- the Kootenai, Clark Fork, Missouri and Yellowstone -- the stream periphyton (bottom) community is more important than the stream plankton (open water) community in terms of plant diversity and plant production. The periphyton community often has more than 300 different kinds of plants (mostly single-celled algae) on one square inch of river bottom.

In unpolluted waters, the dominant algae are diatoms. Diatoms are microscopic, golden-brown plants encased in silica. They are often attached to the river bottom by a short gelatinous stalk. Millions of these creatures underfoot can make a river bottom treacherous, yet they are a sign of good river health. Moreover, they are the preferred food of many aquatic invertebrates.

When a river is polluted and its chemical and biological equilibrium is disturbed, diatoms are often displaced by coarser, less palatable green and blue-green algae (Patrick, 1978). In Montana streams, this take-over is usually accomplished by the long, filamentous green alga Cladophora, which often becomes a nuisance. For this reason we have ranked diatoms relative to other significant algae as a rough index of stream well-being. Theoretically, the lower diatoms are ranked, the more polluted and unbalanced is the river. It should be noted that some non-diatom alga may be seasonally very abundant in nearly pristine streams, for example the blue-green alga Nostoc.

Each one of the many thousand different species of stream diatoms is unique in the conditions it requires for growth. Many of the more common species have been classified as to their general environmental requirements and pollution tolerances (Lowe, 1974). They run the gamut from tolerant to intolerant. Consequently, diatoms are valuable pollution indicators and subtle shifts within the diatom association on a river bottom can signal environmental disturbances long before a stream becomes totally "unglued" and nuisance growths appear.

Achnanthes and Nitzschia are two particularly useful diatom indicators. Achnanthes is almost always found in significant numbers, but only in water having a high concentration of dissolved oxygen, approaching saturation. Nitzschia, on the other hand, is usually associated with waters high in nitrogen. The relative abundance of Nitzschia is often directly proportional to the amount of nitrogen contained in the water. Some species of Nitzschia, such as N. palea, require organic nitrogen for their growth (Cholnoky, 1968).

Clean waters usually have many different species with some fairly common but with none really dominant. Polluted waters have fewer species, often with one or two species very abundant. Clean water is said to have high diversity and polluted water is said to have low diversity. Diversity can be measured simply by counting the number of species in a sample or by calculating a rather involved formula called a diversity index. The most widely

accepted diversity index is the Shannon-Weaver Index or $\bar{d}$. Bahls (In Press) found that benthic diatom associations in unpolluted Montana streams average between 25 and 40 species with $\bar{d}$ values between 3 and 4. Species numbers significantly below 25 and diversity values significantly below 3 are indications of pollution.

Methods

Periphytic algae were collected from natural substrates on the stream bottom. Quantities of larger, macroscopic species were picked in proportion to their abundance relative one to one another and to the attached diatom (slime) community as a whole. Accordingly, an appropriate amount of the diatom community was collected by scraping rocks and other submerged substrates with a razor blade, pocket knife or scalpel. Different substrates in turn were scraped in proportion to their areal coverage. An effort also was made to collect algae from both pools and riffles, again in proportion to the extent these stream features prevail at a given site. The ultimate objective is to obtain a sample of algae that is a miniature replicate of the stream's periphyton community. Samples were preserved with Lugol's (IKI) solution and returned to the lab for analyses.

Conspicuous non-diatom algae were removed, examined microscopically, and identified to genus. The relative abundance and rank of each significant non-diatom genus and the diatom community as a whole were then recorded. A portion of the diatom community was used to prepare a permanent, randomly strewn mount using sulfuric acid and potassium dichromate as the oxidizing agents and Cargille's "Carmount-165" as the mounting medium (A.P.H.A., 1975). A diatom species proportional count was performed on each slide following the technique outlined by Weber (1973), except that in excess of 300 rather than 250 cells were tallied. The results were used to compute percent relative abundance of indicator taxa and diatom species diversity using the Shannon-Weaver formula recommended by Weber (1973):

$$\bar{d} = \frac{C}{N} (N \log_{10} N - \sum n_i \log_{10} n_i)$$

where $C = 3.321928$; N = total number of individuals; and n_i = number of individuals in the i th species.

Results

Parameters depicting periphyton community structure are presented in Tables 16 through 21.

Interpretation

Diatoms dominated the periphyton of most streams in the Southwest Loop (Table 16). However, diatoms were substantially outranked by other algae in Muddy Creek in summer and Prickly Pear Creek above Lake Helena in fall, indicating serious perturbations in these streams at these times. Of the dominant non-diatom algae in southwest Montana streams, the genus Cladophora occurred most frequently (7 times), followed by Phormidium (3), Nostoc and Audouinella (2), and Pleurocapsa and Stigeoclonium (1).

Water quality requirements of major diatom species from the Southwest Loop are summarized in Appendix G. Most of these species (Table 17) indicate circumneutral to somewhat alkaline water approaching eutrophic conditions. Indicators of more severe cases of eutrophication -- Navicula lamii (NALA) and Nitzschia epiphytica (NIEP) -- were abundant in Grasshopper Creek and Prickly Pear Creek. Achnanthes minutissima (ACMI) was the most abundant diatom in the southwest streams. This is a cosmopolitan species but it thrives only in streams with a dissolved oxygen content close to saturation (Cholnoky, 1968).

Total relative abundance values for all Achnanthes species (oxygen indicators) are listed in Table 18. Muddy Creek had the lowest mean value, followed by Grasshopper Creek and the East Gallatin River. Prickly Pear Creek above Lake Helena also had extremely low values for the summer and fall runs. Of all the streams in the Southwest Loop, these are the four most likely to suffer from depressed dissolved oxygen concentrations.

Total relative abundance values for all Nitzschia species (nitrogen indicators) are listed in Table 19. The East Gallatin River and Grasshopper Creek had the highest mean values, reflecting the influence of the relatively high total nitrogen loads in these streams on their periphytic floras. The Ruby and Jefferson rivers had the lowest mean Nitzschia values.

Prickly Pear Creek above Lake Helena had the fewest diatom species and the lowest diatom diversity, on the average, of all stations in the Southwest Loop (Tables 20 and 21). Both values were well below those found to be typical of unpolluted waters in Montana (Bahls, In Press). Streams with mean diversity values indicating borderline water quality were the Boulder and Clark Fork rivers, Prickly Pear Creek at East Helena, and Muddy and Silver Bow creeks.

Table 16. Estimated rank of diatoms and other significant algae, by volume.

Station	Summer	Fall	Spring
Beaverhead River	1. Diatoms 2. Cladophora 3. Oedogonium 4. Oscillatoria	1. Diatoms 2. Cladophora	1. Diatoms 2. Cladophora 3. Oscillatoria
Big Hole River	1. Diatoms 2. Cladophora 3. Scenedesmus 4. Stigeoclonium 5. Cosmarium 6. Pediastrum	1. Diatoms 2. Cladophora 3. Oedogonium 4. Stigeoclonium 5. Ulothrix	1. Diatoms 2. Ulothrix
Boulder River	1. Phormidium 2. Diatoms 3. Vaucheria	1. Diatoms 2. Stigeoclonium 3. Oscillatoria 4. Vaucheria 5. Scenedesmus	1. Diatoms 2. Oscillatoria 3. Stigeoclonium 4. Ulothrix
Clark Fork River	1. Diatoms 2. Nostoc 3. Oscillatoria	1. Cladophora 2. Diatoms 3. Ulothrix 4. Oscillatoria	1. Diatoms 2. Ulothrix
East Gallatin River	1. Diatoms 2. Cladophora 3. Oscillatoria	1. Diatoms 2. Cladophora 3. Oscillatoria	1. Diatoms 2. Hydrurus 3. Ulothrix 4. Closterium
Grasshopper Creek	1. Diatoms 2. Nostoc 3. Cosmarium 4. Anabaena 5. Cladophora	ICE	1. Diatoms 2. Cladophora
Jefferson River	1. Cladophora 2. Diatoms 3. Scenedesmus	ICE	1. Diatoms
Madison River	1. Cladophora 2. Diatoms 3. Spirogyra 4. Hormidium 5. Pediastrum	1. Diatoms 2. Cladophora 3. Ulothrix	1. Diatoms
Muddy Creek	1. Cladophora 2. Nostoc 3. Diatoms 4. Anabaena	ICE	1. Diatoms

Table 16. (Continued)

Station	Summer	Fall	Spring
Prickly Pear Creek/ Lake Helena	1. Audouinella 2. Diatoms 3. Cladophora 4. Stigeoclonium 5. Pleurocapsa	1. Cladophora 2. Phormidium 3. Stigeoclonium 4. Diatoms 5. Oscillatoria	1. Audouinella 2. Diatoms
Prickly Pear Creek/ East Helena	1. Pleurocapsa 2. Diatoms 3. Phormidium 4. Oscillatoria 5. Scenedesmus	1. Phormidium 2. Diatoms	1. Diatoms 2. Phormidium 3. Oscillatoria 4. Ulothrix
Red Rock River	1. Cladophora 2. Diatoms 3. Rivularia	Ice	1. Diatoms
Ruby River	1. Diatoms 2. Cladophora	1. Diatoms 2. Cladophora	1. Diatoms
Sheep Creek	1. Diatoms 2. Cladophora 3. Vaucheria 4. Oedogonium	1. Diatoms 2. Vaucheria 3. Nostoc 4. Cladophora 5. Anabaena	1. Diatoms 2. Vaucheria 3. Nostoc
Silver Bow Creek	1. Diatoms 2. Stigeoclonium 3. Cladophora	1. Cladophora 2. Diatoms 3. Oscillatoria 4. Stigeoclonium 5. Scenedesmus	1. Diatoms 2. Oscillatoria
W. Fork Madison	1. Diatoms 2. Oscillatoria 3. Closterium	1. Diatoms 2. Nostoc 3. Anabaena 4. Hydrurus 5. Oscillatoria	1. Nostoc 2. Diatoms 3. Stigeoclonium 4. Phormidium 5. Oscillatoria 5. Anabaena
West Gallatin River	1. Diatoms 2. Zygnema 3. Cladophora 4. Ulothrix 5. Scenedesmus	1. Diatoms 2. Ulothrix	1. Diatoms 2. Hydrurus 3. Ulothrix 4. Closterium

Table 17. Percent relative abundance of major diatom species (Appendix G)

Station	Summer	Fall	Spring
Beaverhead River	ACMI: 20.0 AMPE: 11.7	ACMI: 31.0	ACMI: 37.7 AMPE: 10.5
Big Hole River	EPSO: 40.7	NIPA: 20.2 EPSO: 14.8 FRVA: 14.0 SYMA: 14.0	FRBR: 17.4 NIFR: 13.6
Boulder River	SYRU: 26.5 ACMI: 20.1 NAMI: 16.0 ACLI: 12.0	ACLI: 29.5 ACMI: 23.1 NAMI: 11.6	ACLI: 20.1 FRVA: 15.1 NAAR: 15.1
Clark Fork River	ACMI: 47.0 NIPA: 13.1	FRVA: 33.2 ACMI: 23.9 NAMI: 14.1	ACMI: 46.8 NAMI: 15.8
East Gallatin River	NACR: 21.8	NATR: 32.8 NIDI: 21.8	NIDI: 23.0 NATR: 16.1
Grasshopper Creek	EPSO: 19.4 NIPA: 15.5 NACR: 14.9 CYME: 13.9	ICE	NALA: 15.7 NIEP: 14.6 NIDI: 12.1
Jefferson River	EPSO: 17.7 FRCO: 17.4	ICE	SUOV: 12.8 NAVI: 10.9
Madison River	EPSO: 31.6	SYMA: 18.0 NIDI: 11.6 FRBR: 10.7	FRVA: 30.7
Muddy Creek	EPSO: 36.0 NIPA: 15.9 NACR: 13.4	ICE	FRVA: 31.6 GOOL: 15.5 NIDI: 14.7 NAVI: 10.6
Prickly Pear Creek/ Lake Helena	NAMI: 46.8 NALA: 19.3	NAMI: 41.5 NALA: 10.6	NAMI: 52.8 ACMI: 15.7 NALA: 10.7
Prickly Pear Creek/ East Helena	NIPA: 30.2 ACMI: 21.4 NAMI: 11.8	ACMI: 22.0 NALA: 18.3 NIPA: 16.8	ACMI: 36.5 NAAR: 24.3 NIPA: 14.7

Table 17. (Continued)

Station	Summer	Fall	Spring
Red Rock River	FRCO: 18.3 AMPE: 15.5	ICE	FRCO: 24.1
Ruby River	ACMI: 32.5 NACR: 10.6	ACMI: 31.8 DIVU: 24.0	ACMI: 21.7 NATR: 17.0
Sheep Crdek	EPSO: 11.6	ACMI: 36.1	ACMI: 45.8
Silver Bow Creek	ACMI: 23.8 NIPA: 22.6 SYUL: 14.6	ACMI: 33.3 NIPA: 23.3 FRVA: 18.2	ACMI: 49.0 GOPA: 16.4 NIPA: 13.5
West Fork Madison River	NACR: 14.3 NIFR: 10.0	ACMI: 16.1	ACMI: 54.9
West Gallatin River	ACMI: 17.5 NIFR: 15.9 DIVU: 12.1	NIFR: 19.0 ACMI: 17.3 NIDI: 10.6	ACMI: 27.3 NIFR: 25.1

Table 18. Percent relative abundance of Achnanthes species

Station	Summer	Fall	Spring	Mean
Beaverhead River	20.3	31.6	38.9	30.3
Big Hole River	6.5	7.4	8.1	7.3
Boulder River	32.4	52.6	29.0	38.0
Clark Fork River	48.6	25.0	48.6	40.7
East Gallatin River	1.1	3.7	8.1	4.3
Grasshopper Creek	3.2	Ice	4.2	3.7
Jefferson River	4.3	Ice	8.1	6.2
Madison River	5.4	3.4	7.9	5.6
Muddy Creek	0.5	Ice	0.9	0.7
Prickly Pear Creek/ Lake Helena	3.4	4.8	21.7	10.0
Prickly Pear Creek/ East Helena	28.0	30.8	37.4	32.1
Red Rock River	7.0	Ice	5.3	6.2
Ruby River	33.1	32.1	23.2	29.5
Sheep Creek	8.1	37.3	46.4	30.6
Silver Bow Creek	35.1	36.6	53.8	41.8
W. Fork Madison River	6.8	18.2	55.8	26.9
West Gallatin River	18.6	18.1	30.6	22.4
Mean	15.4	23.2	25.2	21.1

Table 19. Percent relative abundance of Nitzschia species

Station	Summer	Fall	Spring	Mean
Beaverhead River	12.7	12.3	8.7	11.2
Big Hole River	19.5	29.0	27.9	25.5
Boulder River	10.5	10.9	10.4	10.6
Clark Fork River	23.7	6.8	9.2	13.2
East Gallatin River	33.0	26.0	38.9	32.6
Grasshopper Creek	25.2	Ice	35.4	30.3
Jefferson River	6.9	Ice	11.3	9.1
Madison River	13.8	28.8	15.0	19.2
Muddy Creek	30.2	Ice	21.0	25.6
Prickly Pear Creek/ Lake Helena	10.7	20.3	5.1	12.0
Prickly Pear Creek/ East Helena	32.7	18.6	15.6	22.3
Red Rock River	13.5	Ice	11.6	12.6
Ruby River	5.2	5.8	4.3	5.1
Sheep Creek	16.1	13.8	9.4	13.1
Silver Bow Creek	27.0	28.2	16.3	23.8
W. Fork Madison River	34.7	17.5	17.6	23.3
West Gallatin River	25.9	36.3	27.5	29.9
Mean	20.1	19.6	16.8	18.7

Table 20. Number of diatom species

Station	Summer	Fall	Spring	Mean
Beaverhead River	39	38	36	38
Big Hole River	36	29	32	32
Boulder River	22	24	27	24
Clark Fork River	30	28	26	28
East Gallatin River	34	35	36	35
Grasshopper Creek	47	Ice	34	40
Jefferson River	47	Ice	43	45
Madison River	41	40	42	41
Muddy Creek	34	Ice	22	28
Prickly Pear Creek/ Lake Helena	22	27	14	21
Prickly Pear Creek/ East Helena	26	25	14	22
Red Rock River	64	Ice	81	72
Ruby River	32	36	30	33
Sheep Creek	34	43	35	37
Silver Bow Creek	28	30	15	24
W. Fork Madison River	41	43	32	39
West Gallatin River	41	37	39	39
Mean	36	33	33	34

Table 21. Diatom species diversity ($\bar{d}$).

Station	Summer	Fall	Spring	Mean
Beaverhead River	4.26	3.92	3.61	3.93
Big Hole River	3.58	3.60	4.08	3.75
Boulder River	3.13	3.04	3.56	3.24
Clark Fork River	3.04	3.06	2.89	3.00
East Gallatin River	4.28	3.53	4.18	4.00
Grasshopper Creek	4.27	Ice	4.14	4.20
Jefferson River	4.39	Ice	4.54	4.46
Madison River	3.91	4.14	3.96	4.00
Muddy Creek	3.29	Ice	3.14	3.22
Prickly Pear Creek/ Lake Helena	2.68	3.30	2.33	2.77
Prickly Pear Creek/ East Helena	3.41	3.47	2.56	3.15
Red Rock River	4.85	Ice	5.11	4.98
Ruby River	3.74	3.38	3.76	3.63
Sheep Creek	4.38	3.86	3.33	3.86
Silver Bow Creek	3.58	3.28	2.48	3.11
W. Fork Madison River	4.63	4.56	2.96	4.05
West Gallatin River	4.44	4.22	3.90	4.19
Mean	3.87	3.64	3.56	3.70

MACROINVERTEBRATE COMMUNITY STRUCTURE

Rationale

Macroinvertebrates comprise the energy link between periphyton and fish in Montana streams. Most organisms in this community of bottom dwellers are immature insects. As with the periphyton, macroinvertebrates are differentially tolerant to pollution, thereby allowing certain groups to be used as indicators. Another characteristic in common with the periphyton is their ability to integrate the effects of a variety of water quality constituents over time. Macroinvertebrate life cycles are considerably longer than those of periphyton organisms: up to three years as compared to just a day or two for diatoms. Consequently, they reflect water conditions over a much longer period of time than do the diatoms.

Of the common aquatic insects in Montana streams, three groups are indicators of waters with little organic pollution and ample dissolved oxygen. These are the stoneflies (Plecoptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera). Another group, the order of true flies (Diptera), has species that are either tolerant or intolerant of pollution. Two remaining orders, the bugs (Hemiptera) and beetles (Coleoptera), are generally considered tolerant of pollution. On closer examination, a number of invertebrates are actually facultative or able to get along in both clean and polluted water (Weber, 1973). For a large number of Montana stream insects, water quality preferences simply are not known. Nevertheless, the relative abundance of organisms in various sensitivity groups is still a valid approximator of water quality conditions.

The number of macroinvertebrate genera and macroinvertebrate genus diversity are more concise and perhaps more valid estimators of macroinvertebrate community health. Wilhm (1970) reported clean waters to have from 11 to 54 species and Shannon-Weaver diversity values from 2.6 to over 4. Polluted streams on the other hand, had diversity values less than 2 and frequently less than 1.

Methods

The technique used for macroinvertebrate collection is a modification of the "unit-effort-traveling-kick" method described by Kinney *et al.* (In Press). The objective is to sample each type of habitat at the designated site in a random fashion, and to apply a similar amount of effort at each station, except where bugs are scarce. Equipped with a long-handled D-frame aquatic net (Ward's 10W0620)*, the sampler works all the major habitat types -- riffles, pools, submerged vegetation, etc. -- by dislodging organisms with his feet and capturing them as they drift downstream. Research has shown this method to have better statistical reproducibility than artificial substrate and Surber samplers in semi-arid regions where the fauna tends to be patchy and sparse (Kinney *et al.*, In Press).

*Approximately 21.5 meshes per inch with 1 mm openings

When an adequate number of insects has been collected, the sampler randomly selects 100 or more specimens from the net and places them in a small jar one-third full of water. Care is taken not to be biased by size of the organism. The jar is then filled with 95 percent ethanol, labelled, and returned to the lab for analysis. (A few drops of glycerine are added if extended storage is required). Organisms were identified to genus wherever possible. Enumeration results were used to compute the percent relative abundance of major insect orders and pollution sensitivity groups (Weber, 1973). Shannon-Weaver diversity was calculated in the same fashion as it was for the diatoms (See "Periphyton Community Structure - Methods").

Results

Macroinvertebrate community parameters are presented in Tables 22 through 25.

Interpretation

Four orders of insects dominated the macroinvertebrate fauna of southwest Montana streams (Table 22): Plecoptera (stoneflies), Ephemeroptera (mayflies), Trichoptera (caddisflies), and Diptera (true flies). One of two notable exceptions was Prickly Pear Creek above Lake Helena where members of the genus Asellus (Order Isopoda, Class Crustacea) comprised a significant portion of the fauna. The other exception was the Red Rock River where amphipod crustaceans (Gammarus and Hyaletella) and water boatmen (Genus Trichocorixa, Family Corixidae, Order Hemiptera) dominated the fauna in summer 1977.

Pollution tolerant taxa were never very abundant in streams of the Southwest Loop (Table 23). However, a considerable percentage of facultative genera or genera whose tolerance is unknown were also recorded, making it extremely difficult to assess water quality. The lowest percentages of known intolerant animals were found in the Red Rock River and the East Gallatin River. Curiously, the highest mean percentage was in Silver Bow Creek.

Four streams averaged 11 or fewer genera and had mean diversity values less than 2.5. They were the Clark Fork and Red Rock rivers and Silver Bow and Muddy creeks (Tables 24 and 25). Individual diversity values in these streams ranged from 1.41 in Silver Bow Creek to 3.29 in the Red Rock River. (The latter stream was in flood in spring 1978, perhaps accounting for the low mean diversity.) On comparing these values with those reported by Whilm (1970) for "streams receiving pollution" (range 0.4 to 1.6), one may conclude that these four "worst case" streams of the Southwest Loop are only slightly to moderately polluted.

Table 22. Mean percent relative abundance of major macroinvertebrate orders

Station	Plecoptera (Stoneflies)	Ephemeroptera (mayflies)	Trichoptera (caddisflies)	Diptera (true flies)	Coleoptera (beetles)	Hemiptera (true bugs)	Miscellaneous
Beaverhead River	17.6	24.6	22.3	29.5	1.7	3.9	0.3
Big Hole River	29.2	11.5	30.0	23.2	3.0	2.8	0
Boulder River	40.9	21.0	8.0	29.3	1.0	0	0
Clark Fork River	25.7	15.3	30.0	25.3	0.4	3.3	0
East Gallatin River	29.1	15.2	30.6	22.6	2.5	0	0
Grasshopper Creek	19.4	20.0	41.4	18.7	0	0	0.5
Jefferson River	14.0	45.5	27.7	5.5	5.2	1.6	0.5
Madison River	13.8	38.3	37.4	6.5	2.2	0	1.7
Muddy Creek	58.8	3.0	13.6	22.4	1.7	0.4	0
Prickly Pear Creek/ Lake Helena	21.9	5.8	15.9	38.5	2.2	0	15.8
Prickly Pear Creek/ East Helena	32.3	5.6	33.7	21.8	5.5	0	1.1
Red Rock River	0	26.3	7.4	37.4	3.8	10.6	14.4
Ruby River	34.0	23.1	23.7	15.5	3.7	0	0
Sheep Creek	11.6	17.1	34.9	30.4	5.2	0	0.8
Silver Bow Creek	10.6	7.5	63.0	15.0	1.9	1.6	0.4
W. Fork Madison River	22.0	21.8	34.4	19.4	1.4	0	1.0
West Gallatin River	25.7	20.7	35.2	17.6	0.5	0	0.2
Mean	23.9	19.0	28.8	22.3	2.5	1.4	2.2

Table 23. Mean percent relative abundance of tolerant, facultative and intolerant macroinvertebrates

Station	Tolerant	Facultative or Unknown	Intolerant
Beaverhead River	1.7	36.7	61.5
Big Hole River	3.0	35.7	61.2
Boulder River	1.3	40.7	57.9
Clark Fork River	0.4	24.4	75.2
East Gallatin River	2.5	63.7	33.8
Grasshopper Creek	0	24.6	75.4
Jefferson River	5.7	55.7	38.6
Madison River	2.8	48.8	48.4
Muddy Creek	2.1	27.1	70.8
Prickly Pear Creek/ Lake Helena	2.2	44.6	53.2
Prickly Pear Creek/ East Helena	5.5	24.2	70.3
Red Rock River	3.8	88.8	7.4
Ruby River	3.7	18.6	77.7
Sheep Creek	5.3	53.8	40.9
Silver Bow Creek	1.9	11.7	86.4
W. Fork Madison River	1.6	42.0	56.3
West Gallatin River	0.7	50.7	48.6
Mean	2.6	40.7	56.7

Table 24. Number of macroinvertebrate genera

Station	Summer	Fall	Spring	Mean
Beaverhead River	14	11	11	12
Big Hole River	13	--	16	14
Boulder River	14	15	14	14
Clark Fork River	10	6	12	9
East Gallatin River	11	12	--	12
Grasshopper Creek	12	--	12	12
Jefferson River	17	--	11	14
Madison River	14	15	14	14
Muddy Creek	13	--	8	10
Prickly Pear Creek/ Lake Helena	16	13	12	14
Prickly Pear Creek/ East Helena	20	14	12	15
Red Rock River	14	--	6	10
Ruby River	15	12	18	15
Sheep Creek	20	18	18	19
Silver Bow Creek	14	8	10	11
W. Fork Madison River	19	17	21	19
West Gallatin River	14	13	17	15
Mean	15	13	13	14

Table 25. Macroinvertebrate genus diversity ($\bar{d}$)

Station	Summer	Fall	Spring	Mean
Beaverhead River	2.78	2.59	2.32	2.56
Big Hole River	2.76	---	3.37	3.07
Boulder River	2.88	3.17	3.21	3.09
Clark Fork River	2.40	2.26	2.66	2.44
East Gallatin River	2.71	2.98	---	2.84
Grasshopper Creek	3.12	---	2.88	3.00
Jefferson River	3.24	---	2.08	2.66
Madison River	2.80	3.32	2.62	2.91
Muddy Creek	2.33	---	2.48	2.40
Prickly Pear Creek/ Lake Helena	3.16	2.91	2.40	2.82
Prickly Pear Creek/ East Helena	3.71	2.97	3.02	3.03
Red Rock River	3.29	---	1.47*	2.38
Ruby River	3.04	3.07	3.28	3.13
Sheep Creek	3.72	3.46	3.03	3.40
Silver Bow Creek	2.61	1.41	1.93	1.98
W. Fork Madison River	3.55	3.55	3.88	3.66
West Gallatin River	3.42	3.12	2.98	3.17
Mean	3.03	2.90	2.72	2.89

*Poor sampling conditions (flooding)

SUMMARY AND CONCLUSIONS

This report presents data for 30 biologically-related water quality parameters at 17 stations over three seasons. There is clearly a need for consolidating this information so that stations in the Southwest Loop can be compared at a glance and prioritized from the standpoint of management urgency. Two such consolidation schemes are presented below:

Both schemes incorporate mean values for the following key indicators:

1. Specific conductance (micromhos @ 25 C)
2. Total soluble inorganic nitrogen (mg/l)
3. Total phosphorus (mg/l)
4. Algal assay control maximum standing crop (mg/l)
5. Chlorophyll a accrual (mg/m²/day)
6. Biomass accrual (mg/m²/day)
7. Autotrophic Index (Biomass accrual/Chlorophyll a accrual)
8. Chlorophyll a/Pheophytin a ratio
9. Carotene/Chlorophyll ratio
10. Percent relative abundance Achnanthes species
11. Percent relative abundance Nitzschia species
12. Number of diatom species
13. Diatom species diversity ($\bar{d}$)
14. Percent relative abundance intolerant macroinvertebrates
15. Number of macroinvertebrate genera $\bar{d}$
16. Macroinvertebrate genus diversity ($\bar{d}$)

In Scheme A, the assumption is made that the least amount of nutrients and production, whatever the cause, is the most desirable case. All mean values are listed in order from lowest to highest for each indicator. Indicators where the highest value is presumed to reflect the best water quality are numbers 8, 9, 10, 12, 13, 14, 15, and 16 in the list above. Indicators where the lowest value is presumed to reflect the best water quality are numbers 1-7 and 11. The station with the extreme (highest or lowest) value indicating the poorest water quality is given a ranking of one for that indicator. The station with the second highest or lowest value indicating the second poorest water quality is then given a rank of two, and so on until all 17 stations are ranked for that indicator. When all 17 stations have been ranked for each of the 16 indicators, ranks for each station are totaled and divided by the number of indicators measured at that station. The resulting composite rank may be used to assess relative biological health among the 17 stations of the Southwest Loop.

Scheme B presumes that moderate amounts of nutrient enrichment and production are desirable and that too much (eutrophication) or too little (natural sterility or man-caused toxicity) production is not good. Scheme B differs from Scheme A in that production-related indicators (numbers 2-6) are ranked according to their divergence from the median value, which is considered optimum. In other words, the station with the median value is given a ranking of 17 and the station with the value most distant from the median is given a ranking

of one. The remaining indicators, which are principally indicators of water quality (#1, 7, 10, 11, and 14), algal condition (#8), and community stability and diversity (#9, 12, 13, 15, and 16), are ranked as they were under system A.

Composite rankings under the two schemes, arranged in order from lowest (worst quality) to highest (best quality) are presented in Table 26.

Only the Madison River station changed significantly in position from one scheme to the other. The Madison had the best water quality under scheme A, but only the eleventh best water quality under scheme B. This difference was due to the exceptionally low nutrient and periphyton production values measured in the river at Three Forks. The authors feel that this is a function of the river's large macrophyte (higher plant) community, which may effectively tie up nutrients and compete with periphytic algae.

The four stations with the worst biological conditions were the same under both rating systems: East Gallatin River near Belgrade, Muddy Creek near Dell, Prickly Pear Creek near Lake Helena, and Silver Bow Creek below the Warm Springs Ponds. All four stations are on relatively small streams having limited capacity for assimilating pollution. All of these streams suffer from significant non-point pollution problems. Three of the four stations are further influenced by municipal wastewater discharges; only Muddy Creek receives no significant wastewater discharge.

On the basis of these composite ratings it may be concluded that most of the serious, biologically-debilitating water quality problems at these monitoring stations derive from a combination of inadequate wastewater treatment and serious non-point sources of pollution. Consequently, installation of technological measures aimed at improving treatment of key municipal wastewater discharges will help improve overall water quality in streams of the Southwest Loop. In the case of Silver Bow Creek, the isolation, removal or treatment of residual mine tailings, e.g., the Colorado tailings, may contribute appreciably to biological recovery. For Muddy Creek, Prickly Pear Creek, and the East Gallatin River, improved land use practices also will be required in order to achieve a reasonable level of biological recovery.

Conditions at these 17 stations cannot be considered totally representative of overall water quality in southwestern Montana. First, a single station on a long stream is almost never representative of that stream's water quality over its entire length. Second, the parameters measured may not reflect the effects of certain forms of pollution, namely chronic, sub-lethal metals or occasional high temperature and dewatering. Third, station selections were made for the purpose of monitoring only the known, more highly visible problems. This resulted in a bias toward the larger, more popular streams. Consequently, the effects of non-point pollution in smaller tributary streams are not fairly represented in this survey.

Table 26. Composite ranking of stations in the Southwest Loop.
Best possible rank = 17; worst possible rank = 1.

WATER QUALITY	SCHEME A		SCHEME B	
	Station	Rank	Station	Rank
POOR	East Gallatin River	4.8	East Gallatin River	4.8
	Muddy Creek	6.0	Muddy Creek	5.4
	Silver Bow Creek	6.3	Prickly Pear Creek/ Lake Helena	5.8
	Prickly Pear Creek/ Lake Helena	6.8	Silver Bow Creek	6.5
FAIR	Clark Fork River	7.9	Red Rock River	7.1
	Beaverhead River	8.2	Clark Fork River	7.6
	Red Rock River	8.3	Madison River	8.5
	Grasshopper Creek	8.4	Grasshopper Creek	8.6
	Prickly Pear Creek/ East Helena	9.2	Prickly Pear Creek/ East Helena	9.2
GOOD	Big Hole River	9.3	Beaverhead River	9.8
	Jefferson River	9.6	Jefferson River	9.8
	Sheep Creek	9.6	Sheep Creek	9.8
	West Fork Madison River	9.8	West Fork Madison River	10.1
	Boulder River	10.0	Big Hole River	10.2
	West Gallatin River	10.6	West Gallatin River	10.8
	Ruby River	10.8	Boulder River	10.9
	Madison River	11.2	Ruby River	11.8

LITERATURE CITED

- American Public Health Association, *et al.* 1971.
Standard Methods for the Examination of Water and Wastewater.
Thirteenth Edition. A.P.H.A., Washington, D.C. 874 pp.
- American Public Health Association, *et al.* 1975.
Standard Methods for the Examination of Water and Wastewater.
Fourteenth Edition. A.P.H.A., Washington, D.C. 1193 pp.
- Bahls, L. L. 1978. Aquatic Studies. *In* U.S.D.A. -- Montana Department of State Lands, Draft EIS, ASARCO Troy Project, Lincoln County, Montana. pp. 126-149.
- Bahls, L. L. In Press. Diatom Diversity in Montana Streams.
Proceedings of the Montana Academy of Sciences, 1978
Annual Meeting, Butte.
- Cholnoky, B. J. 1968. The Ecology of Diatoms from Inland Waters. J. Cramer, Lehre. 699 pp.
- Cholnoky, B. J. National Institute for Water Research, Pretoria, South Africa. Letter to Loren L. Bahls dated February 21, 1971.
- Frieling, M. J. 1977. Application of the Algal Assay to Primary Productivity Studies of the Silver Bow-Clark Fork River System. Honors Paper, Department of Biology, Carroll College, Helena, Montana. 18 pp.
- Kinney, W. L., J. E. Pollard and C. E. Hornig. In Press. Comparison of Macroinvertebrate Samplers as they Apply to Streams of Semi-Arid Regions. Proceedings of the Fourth Joint Conference on Sensing of Environmental Pollutants, November 1977, New Orleans, Louisiana.
- Klarich, D. A. 1976. Estimates of Primary Production and Periphyton Community Structure in the Yellowstone River (Laurel to Huntley, Montana). Water Quality Bureau, Montana Department of Health and Environmental Sciences, Billings. 58 pp.
- Lowe, R. L. 1974. Environmental Requirements and Pollution Tolerance of Freshwater Diatoms. EPA-67/4-74-005. 334 pp.
- Mackenthun, K. M. 1969. The Practice of Water Pollution Biology. Federal Water Pollution Control Administration, U. S. Department of the Interior, Washington, D. C. 281 pp.
- Margalef, R. 1969. Ecological Correlations and the Relationship Between Primary Productivity and Community Structure. *In* Goldman, C. R., ed., Primary Productivity in Aquatic Environments, University of California Press, Berkeley. pp. 357-364.

Literature Cited (Continued)

- Miller, W. E., J. C. Greene, and T. Shiroyama. 1978. The *Selenastrum capricornutum* Printz Algal Assay Bottle Test: Experimental Design, Application, and Data Interpretation Protocol. Corvallis Environmental Research Laboratory, U. S. Environmental Protection Agency, Corvallis, Oregon. 126 pp.
- Muller, W. 1953. Nitrogen Content and Pollution of Streams. Water Pollution Abstracts, Volume 28, No. 2. Abstract No. 454.
- Odum, E. P. 1963. Ecology. Holt, Rinehart and Winston, New York. 152 pp.
- Patrick, R. 1977. The Importance of Monitoring Change. In Cairns, J., K. L. Dickson, and C. F. Westlake, eds. Biological Monitoring of Water and Effluent Quality. American Society for Testing and Materials, Philadelphia. pp. 157-189.
- Patrick, R. 1978. Effects of Trace Metals in the Aquatic Ecosystem. American Scientist, Volume 66, No. 2. Pp. 185-191.
- Patrick, R. and C. W. Reimer. 1966. The Diatoms of the United States. Volume 1. Monograph No. 13, The Academy of Natural Sciences of Philadelphia. 688 pp.
- Patrick, R. and C. W. Reimer. 1975. The Diatoms of the United States. Volume 2, Part 1. Monograph No. 13, The Academy of Natural Sciences of Philadelphia. 213 pp.
- Schoeman, F. R. 1973. A Systematical and Ecological Study of the Diatom Flora of Lesotho with Special Reference to the Water Quality. National Institute for Water Research, Pretoria, South Africa. 355 pp.
- U. S. Environmental Protection Agency. 1971. Algal Assay Procedure: Bottle Test. Pacific Northwest Water Laboratory, Corvallis, Oregon. 82 pp.
- U. S. Environmental Protection Agency. 1974. Methods for Chemical Analysis of Water and Wastes. EPA-625/6-74-003. 298 pp.
- Water Quality Bureau. 1976. Water Quality in Montana. Montana Department of Health and Environmental Sciences, Helena. 36 pp.
- Weber, C. I. (ed.). 1973. Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. National Environmental Research Center, U.S.E.P.A., Cincinnati, Ohio.
- Whittaker, R. H. 1970. Communities and Ecosystems. The Macmillan Company, Collier-Macmillan Limited, London. 158 pp.
- Wilhm, J. L. 1970. Range of Diversity Index in Benthic Macro-invertebrate Populations. Journal of the Water Pollution Control Federation, Volume 42, No. 2., Part 2. Pp. R221-R224.

Literature Cited (Continued)

Zison, S. W., K. F. Haven, and W. B. Mills. 1977. Water
Quality Assessment, A Screening Method for Nondesignated 208 Areas.
EPA-600/9-77-023. 549 pp.

RECENT REPORTS ON STREAM WATER QUALITY

IN SOUTHWEST MONTANA

- Anonymous. 1975. Water Pollution -- Gallatin County, Montana. Water Quality Bureau, Helena. 5 pp.
- Anonymous. 1975. Water Pollution -- Madison County, Montana. Water Quality Bureau, Helena. 4 pp.
- Anonymous. 1978. Biological Survey of the Clark Fork River, Montana -- August 12-23, 1974. U. S. Environmental Protection Agency, Denver. 42 pp.
- Bahls, L. L. 1978. Streamflow and Water Quality in the Lower Big Hole River -- Summer 1977. Water Quality Bureau, Helena. 16 pp.
- Beuerman, D., and R. Gleason. 1978. Water Quality of the Silver Bow Creek Drainage; Heavy Metals and Nutrients. Montana College of Mineral Science and Technology, Butte. 107 pp.
- Braico, R. D., and M. K. Botz. 1975. Water Quality Inventory and Management Plan -- Upper Missouri Tributaries Basin, Montana. Water Quality Bureau, Helena, 167 pp.
- Braico, R. D., and M. K. Botz. 1974. Water Quality Inventory and Management Plan -- Missouri-Sun-Smith Basin, Montana. Water Quality Bureau, Helena. 162 pp.
- Casne, E. W., M. K. Botz, and M. J. Pasichnyk. 1975. Water Quality Inventory and Management Plan -- Upper Clark Fork Basin, Montana. Water Quality Bureau, Helena. 148 pp.
- Dent, R. L. 1974. Bottom Fauna Sampling of the Upper Clark Fork River Drainage, Deer Lodge County, Montana. The Anaconda Company, Butte. 11 pp.
- Frieling, M. J. 1977. Application of the Algal Assay to Primary Productivity Studies of the Silver Bow - Clark Fork River System. Biology Department, Carroll College, Helena. 18 pp.
- Gless, E. E. 1973. Ecological Studies of Silver Bow and Blacktail Creeks and Upper Clark Fork River: Silver Bow, Powell and Deer Lodge Counties, Montana. Montana College of Mineral Science and Technology, Butte. 34 pp.
- Ingman, G. L. 1978. A study of the Biological Impact of the Helena Sewage Treatment Plant Effluent on Prickly Pear Creek. Water Quality Bureau. Helena.
- Klages, M. G., and F. T. Adamson. 1975. Effect of Suspended Silt on Dissolved Phosphorus Level in the Gallatin River. Plant and Soils Science Department, Montana State University, Bozeman.

Recent Reports on Stream Water Quality in Southwest Montana (Continued)

- Knudson, K., and K. Hill. 1978. An Investigation to Define Minimum Stream Flows Necessary to Sustain the Fish and Wildlife Resources of the Upper Clark Fork River. Montana Department of Fish and Game, Helena. 42 pp.
- Luedtke, R. J., D. M. Gillespie, and R. V. Thurston. 1974. Macroinvertebrate Distribution in the East Gallatin River, Montana. Fisheries Bioassay Laboratory, Montana State University, Bozeman. 47 pp.
- Neher, M. A., and G. F. Weisel. 1977. Heavy Metal Accumulation and its Effect on the Biota of an Industrial Settling Pond. Zoology Department, University of Montana, Missoula. 96 pp.
- Pedersen, R. 1977. An Assessment of Mining Impacts on Water Quality in the Northern Boulder Batholith. Water Quality Bureau, Helena. 53 pp.
- Russo, R. C., and R. V. Thuston. 1975. Water Analysis of the East Gallatin River (Gallatin County) Montana -- 1974. Fisheries Bioassay Laboratory, Montana State University, Bozeman. 25 pp.
- Stuart, D. G., et al. 1974. Gallatin Basin Waste Allocation Study. Biology Department, Montana State University, Bozeman. 82 pp.
- VanMeter, W. P. 1974. Heavy Mineral Concentration in Fish Tissue of the Upper Clark Fork River. Chemistry Department, University of Montana, Missoula.

APPENDICES

Appendix A. Streams and stations in the Montana biological monitoring network

SOUTHWEST LOOP

Completion Year: 1978

Beaverhead River at Twin Bridges
Big Hole River near Twin Bridges
Boulder River below Boulder
Clark Fork River at Deer Lodge
East Gallatin River at Thompson Creek
Grasshopper Creek near mouth
Jefferson River near Three Forks
Madison River near Three Forks
Muddy Creek at mouth near Dell
Prickly Pear Creek above Lake Helena
Prickly Pear Creek at East Helena
Red Rock River above Lima Reservoir
Ruby River near Twin Bridges
Sheep Creek above Muddy Creek
Silver Bow Creek below Warm Springs Ponds
West Fork Madison River near mouth
West Gallatin River at Central Park

NORTHCENTRAL LOOP

Completion Year: 1978

Big Sandy Creek near mouth
Dearborn River near mouth
Lodge Creek near Chinook
Marias River at Loma
Marias River at Shelby WTP intake
Milk River above Chinook
Milk River at Havre WTP intake
Missouri River at Fort Benton WTP intake
Missouri River at Cascade
Muddy Creek near mouth at Vaughn
Pondera Creek near mouth
Smith River near Ulm
Sun River below Vaughn
Sun River near Fort Shaw
Teton River at Loma
Teton River north of Dutton

NORTHWEST LOOP

Completion Year: 1979

Bitterroot River at Maclay Bridge
Clark Fork River at Huson RR Bridge
Clark Fork River below Bonner Dam
Clearwater River at mouth
Fisher River at mouth
Flathead River at mouth

Appendix A. (Continued)

NORTHWEST LOOP (Continued)

Flathead River above Flathead Lake
Lake Creek at mouth
Little Blackfoot River at Avon
Middle Fork Flathead River near mouth
North Fork Flathead River at mouth
Swiftcurrent Creek near Babb
Stillwater River near Kalispell
Swan River near mouth
Whitefish River near Kalispell
Yaak River at mouth

NORTHEAST LOOP

Completion Year: 1980

Beaver Creek near Saco
Box Elder Creek near Winnett
Big Muddy Creek near Culbertson
Big Spring Creek below Lewistown
Judith River near Danvers
Judith River near Utica
Milk River at Nashua
Missouri River at Culbertson
Musselshell River at Mosby
Poplar River at mouth
Redwater River near mouth
Redwater River at Circle
Wolf Creek at Denton

SOUTHEAST LOOP

Completion Year: 1981

Armell's Creek near Colstrip
Beaver Creek at Wibaux
Bighorn River at Bighorn
Clark's Fork River at Laurel
Little Missouri River at Capitol
Musselshell River at Delphia
Musselshell River at Bundy
Powder River near mouth
Powder River at Broadus
Rosebud Creek near Colstrip
Shields River near mouth
Tongue River at Miles City
Tongue River at Ashland
Yellowstone River at Glendive
Yellowstone River at Huntley Dam
Yellowstone River at U.S.G.S. Station in Billings
Yellowstone River at Livingston

Appendix B. Phosphate (PO_4 as P in mg/l)

Station	Summer	Fall	Spring	Mean
Beaverhead River	0.005	0.009	0.033	0.016
Big Hole River	0.013	0.012	0.065	0.030
Boulder River	0.014	0.039	0.070	0.041
Clark Fork River	0.004	0.015	0.098	0.039
East Gallatin River	0.120	0.180	0.195	0.165
Grasshopper Creek	0.079	0.058	0.188	0.108
Jefferson River	0.001	0.005	0.029	0.012
Madison River	0.009	0.014	0.033	0.019
Muddy Creek	0.010	Ice	0.176	0.093
Prickly Pear Creek/ Lake Helena	0.310	0.820	0.439	0.523
Prickly Pear Creek/ East Helena	0.012	0.020	0.028	0.020
Red Rock River	0.006	Ice	0.057	0.032
Ruby River	0.001	0.003	0.028	0.011
Sheep Creek	0.002	0.006	0.021	0.010
Silver Bow Creek	0.005	0.010	0.170	0.057
W. Fork Madison River	0.013	0.019	0.031	0.021
West Gallatin River	0.004	0.005	0.028	0.012
Mean	0.036	0.081	0.099	0.072

Appendix C. Total phosphorus (P in mg/l)

Station	Summer	Fall	Spring	Mean
Beaverhead River	0.022	0.040	0.117	0.060
Big Hole River	0.025	0.070	0.135	0.077
Boulder River	0.022	0.040	0.113	0.058
Clark Fork River	0.020	0.110	0.231	0.120
East Gallatin River	0.150	0.200	0.321	0.224
Grasshopper Creek	0.110	0.060	0.372	0.181
Jefferson River	0.016	0.030	0.073	0.040
Madison River	0.025	0.020	0.053	0.033
Muddy Creek	0.026	Ice	0.533	0.280
Prickly Pear Creek/ Lake Helena	0.460	1.600	0.517	0.859
Prickly Pear Creek/ East Helena	0.024	0.020	0.062	0.035
Red Rock River	0.057	Ice	0.120	0.088
Ruby River	0.014	0.020	0.108	0.047
Sheep Creek	0.017	0.010	0.034	0.020
Silver Bow Creek	0.020	0.050	0.314	0.128
W. Fork Madison River	0.018	0.030	0.050	0.033
West Gallatin River	0.010	0.020	0.037	0.022
Mean	0.061	0.155	0.188	0.134

Appendix D. Nitrate plus nitrite ($\text{NO}_3 + \text{NO}_2$ as N in mg/l).

Station	Summer	Fall	Spring	Mean*
Beaverhead River	0.58	0.53	0.51	0.54
Big Hole River	<0.01	<0.01	0.03	0.01
Boulder River	0.09	0.12	0.16	0.12
Clark Fork River	0.28	0.59	0.76	0.54
East Gallatin River	0.61	0.91	0.91	0.81
Grasshopper Creek	<0.01	0.12	0.12	0.08
Jefferson River	<0.01	0.27	0.12	0.13
Madison River	<0.01	0.02	0.04	0.02
Muddy Creek	0.01	Ice	0.03	0.02
Prickly Pear Creek/ Lake Helena	0.55	0.78	0.62	0.65
Prickly Pear Creek/ East Helena	0.07	0.20	0.25	0.17
Red Rock River	<0.01	Ice	0.03	0.02
Ruby River	0.05	0.22	0.21	0.16
Sheep Creek	0.02	0.05	0.06	0.04
Silver Bow Creek	0.03	0.54	0.42	0.33
W. Fork Madison River	<0.01	0.16	0.11	0.09
West Gallatin River	<0.01	0.09	0.07	0.05
Mean *	0.13	0.31	0.26	0.23

*Assumes values less than 0.01 equal zero

Appendix E. Ammonia (NH_3 as N in mg/l)

Station	Summer	Fall	Spring	Mean*
Beaverhead River	<0.01	0.02	0.03	0.02
Big Hole River	<0.01	<0.01	0.02	0.01
Boulder River	<0.01	0.03	0.05	0.03
Clark Fork River	<0.01	0.08	0.20	0.09
East Gallatin River	0.01	0.14	0.13	0.09
Grasshopper Creek	0.01	0.01	0.23	0.08
Jefferson River	<0.01	<0.01	0.02	0.01
Madison River	<0.01	<0.01	0.02	0.01
Muddy Creek	<0.01	Ice	0.03	0.02
Prickly Pear Creek/ Lake Helena	0.42	4.00	0.64	1.69
Prickly Pear Creek/ East Helena	<0.01	0.02	0.03	0.02
Red Rock River	0.02	Ice	0.02	0.02
Ruby River	<0.01	<0.01	0.03	0.01
Sheep Creek	<0.01	0.03	0.02	0.02
Silver Bow Creek	0.02	0.31	0.43	0.25
W. Fork Madison River	<0.01	<0.01	0.02	0.01
West Gallatin River	<0.01	<0.01	0.02	0.01
Mean*	0.03	0.31	0.11	0.14

*Assumes values less than 0.01 equal zero

Appendix F. Kjeldahl nitrogen (N in mg/l)

Station	Summer	Fall	Spring	Mean
Beaverhead River	0.44	0.40	0.63	0.49
Big Hole River	0.32	0.27	0.60	0.40
Boulder River	0.22	0.16	0.51	0.30
Clark Fork River	0.33	0.69	1.00	0.67
East Gallatin River	0.40	0.43	1.31	0.71
Grasshopper Creek	0.59	0.28	1.73	0.87
Jefferson River	0.35	0.23	0.38	0.32
Madison River	0.33	0.19	0.21	0.24
Muddy Creek	0.32	Ice	1.09	0.70
Prickly Pear Creek/ Lake Helena	1.40	3.00	1.50	1.97
Prickly Pear Creek/ East Helena	0.19	0.12	0.16	0.16
Red Rock River	1.20	Ice	1.00	1.10
Ruby River	0.28	0.22	0.65	0.38
Sheep Creek	0.14	0.08	0.26	0.16
Silver Bow Creek	0.41	0.54	0.77	0.57
W. Fork Madison River	0.16	0.10	0.64	0.30
West Gallatin River	0.14	0.08	0.10	0.11
Mean	0.42	0.45	0.74	0.54

Appendix G. Water quality requirements of major diatom species

CODE	SPECIES	WATER QUALITY REQUIREMENTS	REFERENCE(S)
ACLI	<u>Achnanthes linearis</u> (W. Sm.) Grun.	Optimum pH 6.5 - 6.8; 0-15°C; "high oxygen concentrations"	Lowe, 1974
ACMI	<u>Achnanthes minutissima</u> Kutz.	Optimum pH 7.5 - 7.8; "high oxygen concentrations"	Lowe, 1974
AMPE	<u>Amphora perpusilla</u> (Grun.) Grun.	Alkaliphil (pH >7); epilithic (fixed, solid surfaces)	Patrick and Reimer, 1975
CYME	<u>Cyclotella menehiniana</u> Kutz.	Optimum pH 8.0 - 8.5; halophilous; fall maximum	Lowe, 1974
DIVU	<u>Diatoma vulgare</u> Bory	Optimum pH 8.2; eutrophic; winter dominant	"
EPSO	<u>Epithemia sorex</u> Kutz.	Optimum pH 8.3 - 8.5; eutrophic; tolerates some salt	"
FRBR	<u>Fragilaria brevistriata</u> Grun.	Optimum pH 7.5 - 7.8; eutrophic; tolerates some salt	"
FRCO	<u>Fragilaria construens</u> (Ehr.) Grun.	Optimum pH 7.7 - 7.8; eutrophic; fall maximum	"
FRVA	<u>Fragilaria vaucheriae</u> (Kutz.) Peters	Optimum pH 6.5 - 9.0; eutrophic; 0-15°C	"
GOOL	<u>Gomphonema olivaceum</u> (Lyngb.) Kutz.	pH Range 6.4 - 9.0; eutrophic; winter or spring form	"
GOPA	<u>Gomphonema parvulum</u> Kutz.	Optimum pH 7.8 - 8.2; nutrient-rich water	Lowe, 1974; Patrick and Reimer, 1975

Appendix G. (Continued)

CODE	SPECIES	WATER QUALITY REQUIREMENTS	REFERENCE (S)
NAAR	<u>Navicula arvensis</u> Hust.	Optimum pH <6.5; oligotrophic; warm water	Patrick and Reimer, 1966; Schoeman, 1973
NACR	<u>Navicula cryptocephala</u> Kutz.	Optimum pH 8.0; eutrophic; tolerates some salt	Lowe, 1974
NALA	<u>Navicula lamii</u> Manguin	Optimum pH >8.0; eutrophic; high organic nitrogen	Schoeman, 1973
NAMI	<u>Navicula minima</u> Grun.	Optimum pH 7.5 - 8.0; eutrophic; tolerates some salt	Lowe, 1974
NATR	<u>Navicula tripunctata</u> (O. F. Mull.) Bory	Optimum pH 8.3; eutrophic; tolerates some salt	"
NAVI	<u>Navicula vividula</u> (Kutz.) Kutz.	Optimum pH 7.5; eutrophic; tolerates some salt	"
NIDI	<u>Nitzschia dissipata</u> (Kutz.) Grun.	Optimum pH 8.0; eutrophic; tolerates some salt	"
NIEP	<u>Nitzschia epiphytica</u> O. Mull.	Nitrogen heterotroph; "only frequent in polluted waters"	Cholnoky, pers. comm.
NIFR	<u>Nitzschia frustulum</u> Kutz.	pH range 6.2 - 8.6; eutrophic; tolerates broad range of salt	Lowe, 1974
NIPA	<u>Nitzschia palea</u> (Kutz.) W. Sm.	Optimum pH 8.4; eutrophic; 0 - 30°C	"

Appendix G. (Continued)

CODE	SPECIES	WATER QUALITY REQUIREMENTS	REFERENCE(S)
SUOV	<u>Surirella ovata</u> Kutz.	Optimum pH 7.5 - 8.0; 0-24°C; winter maximum	Lowe, 1974
SYMA	<u>Synedra mazamaensis</u> Sov.	pH Range 7.2 - 8.4; reported only from Pacific Northwest	Lowe, 1974; Patrick and Reimer, 1966
SYRU	<u>Synedra rumpens</u> Kutz.	pH Range 6.0 - 9.0; tolerates some salt; widely distributed	"
SYUL	<u>Synedra ulna</u> (Nitz.) Ehr.	pH Range 5.7 - 9.0; eutrophic; tolerates some salt	Lowe, 1974



